Improving Air-Sea Coupling Parameterizations in High-Wind Regimes

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LONG-TERM GOAL

The long-term goal of this PI team is to understand the physical processes of the air-sea interaction and coupling of the atmosphere-ocean system in high-wind maritime regimes, with a particular emphasis on hurricanes, and to determine the changes that must be made to the coupled atmosphere-wave-ocean models in order to simulate the coupled boundary layers under extreme wind conditions.

OBJECTIVES

The main objectives of this study are 1) to develop improved subgrid-scale (SGS) parameterizations for modeling the atmosphere boundary layer (ABL) structure in high-wind regimes using a large-eddy simulation (LES) approach and explore the effects of sea spray on the ABL through LES experiments, 2) to improve drag coefficient calculations for high-wind conditions by parameterizing "spectral tails" (wavelength < 10 m) unresolved by the current wave models, 3) to test the sensitivity of mixing schemes in the ocean mixed layer (OML) and examine the effects of the ocean waves on the OML dynamics, and 4) to develop atmosphere-wave and atmosphere-ocean generic couplers to allow the flexibility of testing various physical parameterizations and different models in the coupled system.

APPROACH

Our current focus is to study the nature of coupled atmosphere-ocean boundary layers and heat and momentum exchange at the air-sea interface in hurricanes. The extreme high winds, intense rainfall, large ocean surface waves, and copious sea spray push the surface-exchange parameters for temperature, water vapor and momentum to untested new regimes. We will develop improved parameterizations of subgrid-scale processes, air-sea exchange coefficients, and surface fluxes in coupled atmosphere-wave-ocean models with high-resolution (~1-2 km grid spacing) that can resolve the hurricane eyewall structure. The RSMAS/UM PI team is focusing on the effects of ocean wave "spectral tails" on drag coefficient, wind-wave coupling, and ocean mixed layer parameterizations. The PSU PI team develops improved parameterizations of subgrid-scale processes in ABL. The methodology is to use a Large-Eddy Simulation (LES) initialized for hurricane-like conditions, including very high winds and the effects of waves at the lower boundary and sea spray. These

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14. ABSTRACT
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parameterizations would then be installed and tested in the coupled atmosphere-wave-ocean models like the coupled modeling system at RSMAS/UM and the U. S. Navy's COAMPS. We will work closely with other CBLAST PI teams working on obtaining new observations of hurricanes to evaluate our model results.

WORK COMPLETED

RSMAS/UM team:

During the first year of this five-year CBLAST project, we have established several key steps toward developing a coupled atmosphere-wave-ocean modeling system for hurricane research and prediction. The components of the coupled systems are the PSU/NCAR MM5, WAVEWATCH III, and the University of Miami HYCOM. First, we have completed a 6-day wave model simulation of Hurricane Floyd (1999) forced by the high-resolution surface winds from MM5. Using a vortex-following, four-level nested grids MM5, we are able to conduct a 6-day long simulation to capture the evolution of rapid intensification and the landfall of Hurricane Floyd at 1.67 km grid resolution on the inner-most domain. The NECP global analysis fields and the high-resolution (~9 km) AVHRR Pathfinder analysis (Chen, et al., 2001) are used to initialize MM5 and provide continuous lateral and lower boundary conditions. The model simulation of Hurricane Floyd has been validated with both the satellite and in situ observations. Second, we developed an atmosphere-wave coupler and conducted several coupled MM5-WAVEWATCH simulations with various coupling schemes, including both non-directional and directional stress coupling, with and without the "spectral tails" parameterization. Third, we compared the model simulated wave spectra with observations from Hurricane Floyd and Bonnie (1998). We have also conducted number of sensitivity simulations using various atmospheric boundary layer schemes to examine the validity of the currently physical parameterizations in the atmospheric models.

PSU team:

Profs. Wyngaard and Frank and Graduate student Mark Kelly have made progress on three fronts: developing a strategy for including surface wave and spray effects through the lower boundary conditions on the LES; incorporating phase change in the code, including fractional condensation on the subgrid scale; and including the dynamic effects of liquid water (sea spray) in the LES equations. We have also begun to develop an approach to the SGS modeling when the grid scale is larger than optimal (i.e., approaching the energy-containing scale range), as may be necessary in hurricane applications. Kelly spent time at NCAR this summer working with Peter Sullivan on the first topic, and he carried out the first studies on the third topic last spring. Prof. Stauffer will work on installing and testing these parameterizations in MM5 and COAMPS.

RESULTS

The high-resolution (~1.6 km grid spacing) MM5 simulation of Hurricane Floyd (1999) shows a complex pattern of surface fluxes near the inner core of the hurricane (Fig. 1). It is different than the patterns seen in the current mesoscale resolution simulations at 15 km or coarser grids, which cannot resolve the eyewall structure. The maximum surface wind in the eyewall region from the 1.6 km simulations is 30-40% higher than the 15 km simulation. The corresponding wave model simulations with the two different wind forcing show a significant difference in both significant wave heights and wave spectra. Model simulated wave spectrum compares well with the observed spectrum in Hurricane Floyd (Fig. 2, see Wright et al., 2000).
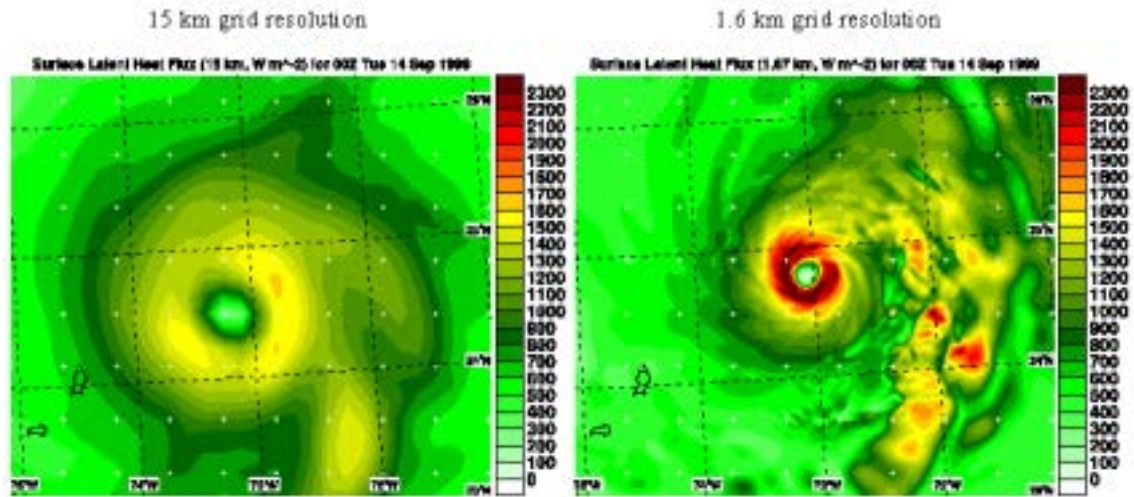
Figure 1. Model simulated surface latent and sensible heat fluxes in Hurricane Floyd (1999) at 15 km (left) and 1.67 km (right) grid spacing, respectively.
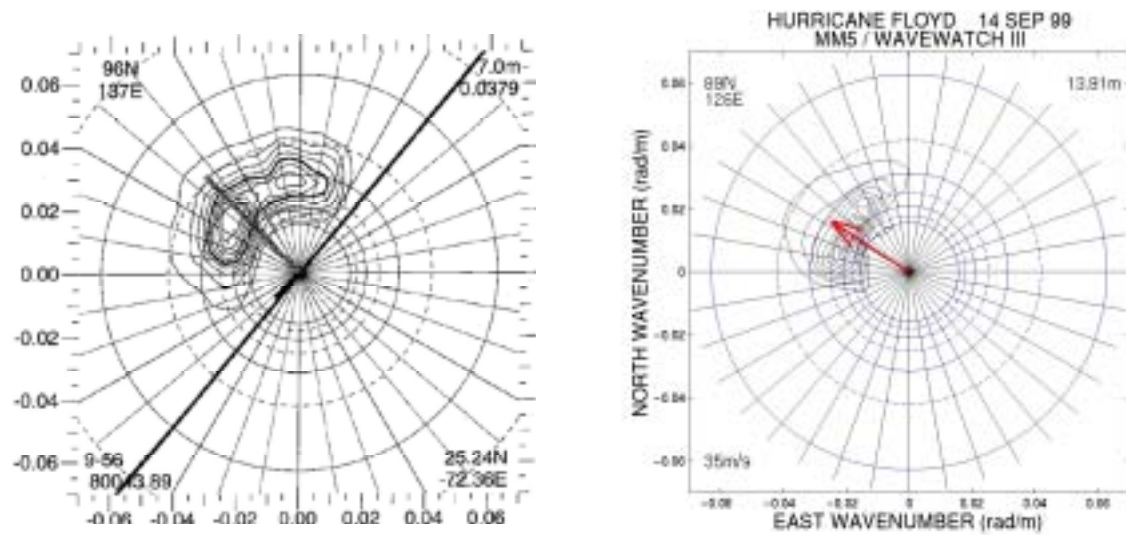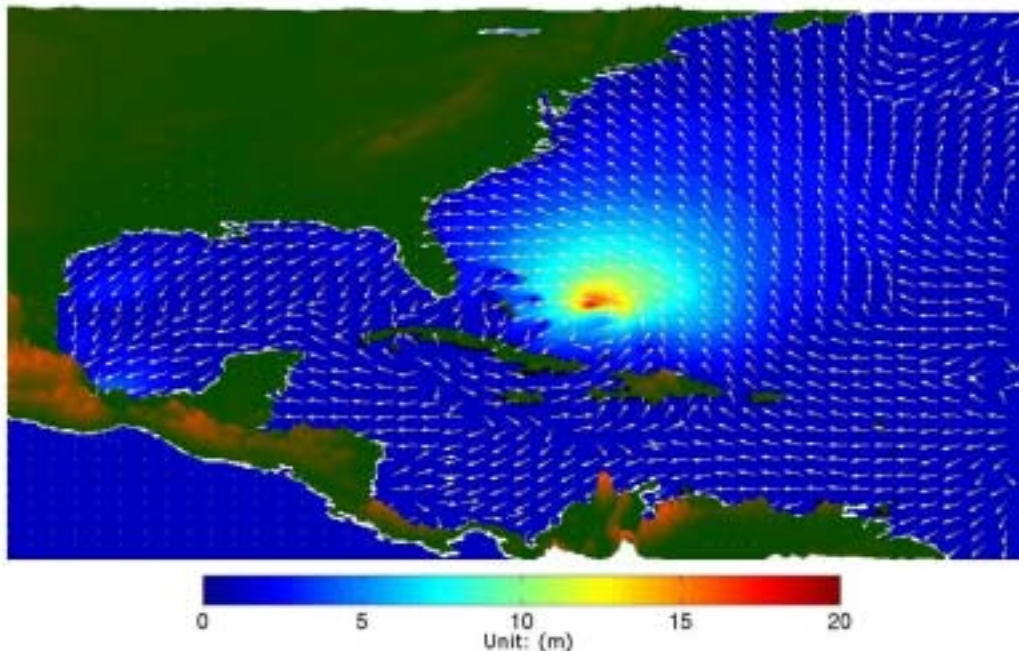

Figure 2. Observed (left) and model simulated (right) ocean surface wave spectra in Hurricane Floyd (1999).

Significant Wave Height / Wave Direction 19990914 06Z (Hurricane Floyd)

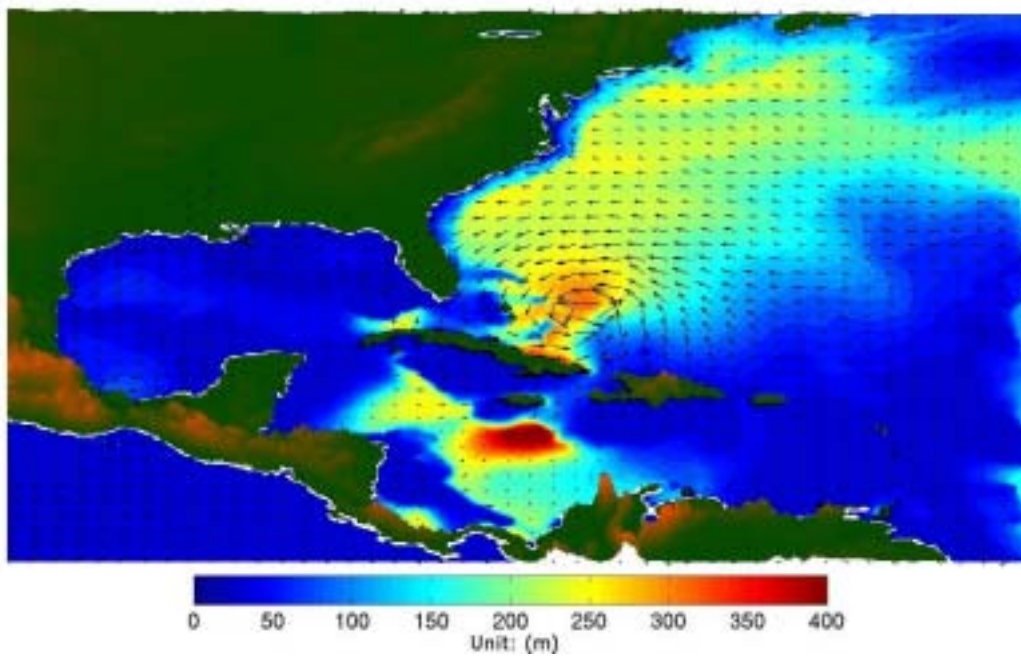Wave Length / Surface Wind 19990914 06Z (Hurricane Floyd)

Figure 3. Model simulated significant waveheight (SWH) and wave propagation direction (upper panel) and wavelength and surface winds (lower panel) associated with Hurricane Floyd (1999).

The spatial variations of SWH and wavelength around an intense hurricane are highly complex (Fig. 3). The wave-dependent drag coefficient is more asymmetric than in the uncoupled simulation. The model simulated hurricane intensity is quite sensitive to various surface parameterizations.

IMPACT/APPLICATIONS

Over the last a few decades hurricane track forecasts have improved significantly, whereas very little progress made in hurricane intensity forecasts. The lack of the skill in the intensity forecasts can be attributed, in part, to deficiencies in the current operational prediction models: insufficient model resolution, inadequate surface and boundary layer formulations, and lack of full coupling to the ocean. This project will provide improved physical parameterizations for the coupled atmosphere-wave-ocean models at very high spatial resolution. It will make a significant contribution to improve hurricane intensity predictions.

TRANSITIONS

We will assist in the transitioning of the completed parameterizations to operational coupled modeling systems (e.g., COAMPS). These new parameterizations developed at RSMAS/U.Miami and Penn State will be made available for all ONR CBLAST PIs.

RELATED PROJECTS

Related projects include the NSF/NOAA/ONR USWRP on Rainfall of Hurricanes at Landfall (S. Chen), the NASA/JPL QuikSCAT (S. Chen), ONR HYCOM Consortium for Data Assimilative Ocean Modeling (E. Chassignet, G. Halliwell, et al.), and ONR CBLAST-Hurricane (P. Black et al.).

REFERENCES

Chen, S. S., W. Zhao, J. E. Tenerelli, R. H. Evans, and V. Halliwell, 2001: Impact of the AVHRR sea surface temperature on atmospheric forcing in the Japan/East Sea, *Geophys. Res. Letters*, in press.

Wright, C. W., E. J., Walsh, D. C. Vandemark, and W. B. Krabill, 2000: Hurricane directional wave spectrum spatial variation in the open ocean, Preprints, 24th Conference on Hurricanes and Tropical Meteorology, 29 May-2 June 2000, Ft. Lauderdale, AMS, J1-3.